

## Near-Infrared Galaxy Surveys in 2D, 3D & 4D

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**Abstract.** The completeness and reliability of the DENIS *IJK* survey and the EDSGC (derived from the COSMOS scans of USKT plates) are obtained by detailed cross-identifications and systematic visual inspections of conflictual classifications. The DENIS galaxy extraction turns out to be over 95% complete and reliable out to  $I < 16$ , while the COSMOS/EDSGC galaxy catalogue is less than 80% complete and reliable at  $B_J = 17.5$ , and even less than 10% complete at  $B_J < 14.5$ .

Spectroscopic followups of DENIS and the similar Near-IR 2MASS survey are described: 1) a redshift survey of 120,000 galaxies using the 6dF robotic multi-fiber spectrograph, currently under construction at the UKST, and for which a total of 300 nights are guaranteed for 2001-2003, 2) a peculiar velocity survey of 12,000 early-type galaxies with the 6dF, and 3) the DENIS-HI peculiar velocity survey of 5000 inclined spirals visible from Nançay ( $\delta > -38^\circ$ ), which has just begun. The DENIS-HI and 6dF peculiar velocity samples will have the strong advantage of covering entire regions of the southern sky, and combined, will multiply by 10 and 4 respectively the projected and space number densities of objects in the Southern sky. These two surveys should thus provide considerably more accurate estimates of the bulk flow,  $\Omega_{\text{matter}}^{0.6}/\text{bias}$ ,  $\Omega_{\text{matter}}$  itself, and the primordial density fluctuation spectrum.

### 1. Near-infrared surveys and cosmology

As is well known, near-infrared (NIR) photons are up to 10 times less affected by dust extinction than their visible counterparts. Hence, cosmological surveys based upon NIR-selected galaxy samples can probe the Universe almost completely through the Zone of Avoidance in the Galactic Plane, and moreover have a clearer view of galaxies, virtually unobscured by dust (especially important for the central regions of spirals and for edge-on spirals).

The other main advantage of NIR-selected galaxy samples is that they are not biased towards recent star formation, contrary to optically-selected samples (especially in blue light), and hence the NIR-selected galaxies are more weighed by their mass, or at least their stellar mass.

However, the IRAS galaxy samples, heavily weighted towards galaxies with recent star formation, appear to be better tracers of the mass in the Universe

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than are early-type galaxy samples. The first spectroscopic followups of NIR selected galaxy samples show fairly small fractions of galaxies with emission lines in their spectra: 37% in  $J < 13.7$  samples (Mamon et al. 1999) and 30% in  $K < 12.2$  samples (Huchra, 1999), in comparison with 60% in similar depth  $B$ -selected samples. Hence, DENIS and 2MASS will be more weighted towards early-type galaxies and may lead to stronger biases relative to the dark matter than the IRAS samples, but this remains to be seen (especially because, contrary to the IRAS samples, they will have a mix of early- and late-type galaxies).

## 2. DENIS

The DENIS (DEep Near Infrared Southern Sky Survey) consortium is undertaking a complete imaging survey of the southern sky ( $-88^\circ < \delta < +2^\circ$ ) in the Gunn  $I$  ( $0.8\mu$ ), Johnson  $J$  ( $1.25\mu$ ), and  $K_s$  ( $2.15\mu$ ) bands (Epchtein et al. 1997), and at this writing, 62% of the southern sky has been observed (see <http://www.iap.fr/users/gam/DENIS/slots.html>). The completion date is planned for January 2001. The DENIS team has built an IR camera and mounted it on the ESO 1m telescope (which had previously only done optical aperture photometry). The  $I$ ,  $J$ , and  $K$  images are obtained simultaneously through the use of dichroics with integration times of 9 sec. The pixel sizes are  $1''$  in  $I$  and  $3''$  in  $J$  and  $K$ , and the latter two are dithered in 9 sub-exposures of 1 sec each to yield images with a pseudo-resolution of  $1''$ .

Star/galaxy separation is performed with classical estimators, and except in the Zone of Avoidance ( $|b| < 2^\circ$ ), the much higher sensitivity and spatial resolution of the  $I$  band allow us to base our star/galaxy separation on the  $I$  images for objects detected in the  $J$  or  $K$  images.

## 3. Comparison of DENIS and COSMOS/EDSGC galaxy extractions

We have performed detailed cross-identifications of the DENIS extractions with the COSMOS extractions from  $B_J$  photographic plates (obtained over the World Wide Web), over 8 DENIS strips, corresponding to  $50\text{ deg}^2$ . These strips were randomly selected at typically high galactic latitudes ( $\langle |b| \rangle \simeq 50^\circ$ ) from the great majority of strips that are not flagged as poor quality.

To compare the quality of the two surveys, we performed two cross-identifications: 1) relative to all DENIS objects; and 2) relative to COSMOS objects ( $B_J < 20.5$ ) in the exact geometry of the 8 DENIS strips. We assumed that all objects, on which both DENIS and COSMOS agreed were galaxies, were indeed galaxies. We systematically inspected visually the DENIS  $I$ -band images for all cases with  $I < 16$  (our estimated limit for 95% reliable visual classification) where one of the surveys identified a galaxy while the other called it a star or did not detect it altogether. Objects that both DENIS and COSMOS classify as galaxies have  $\langle B - I \rangle = 2.3$  and 95% have  $B - I > 1.5$ . Hence, our estimates of COSMOS completeness are limited to  $B < 17.5$ .

Figure 1 shows the resulting DENIS (*left*) and COSMOS (*right*) completeness (*dashed*) and reliability (*solid*) as a function of magnitude. While DENIS achieves better than 95% completeness and reliability over the full range  $13 < I < 16$ , COSMOS has worse than 80% completeness and reliability at

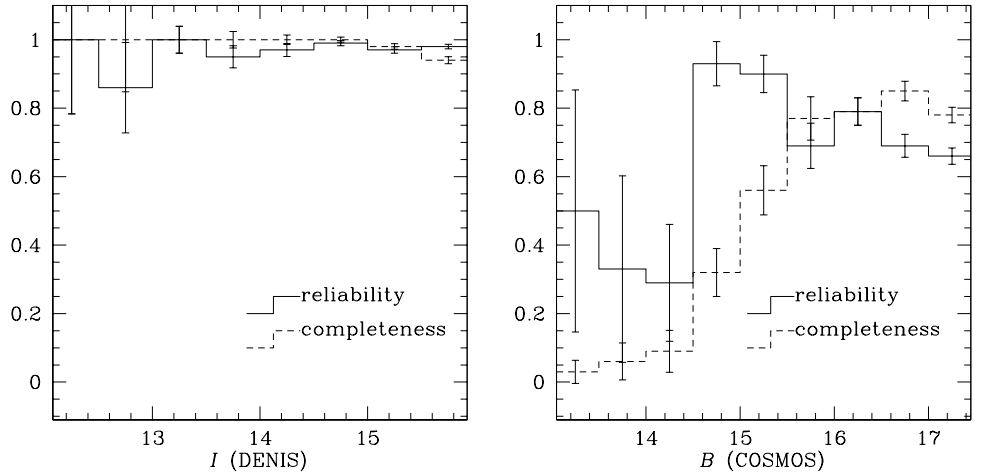


Figure 1. Completeness (*dashed*) and reliability (*solid histograms*) for DENIS (*left*) and COSMOS (*right*) galaxy extraction.

$B = 17.5$ , and the numbers get even worse at brighter magnitudes: in particular the completeness falls to below 10% at  $B < 14.5$ . At bright magnitudes, COSMOS suffers from the non-linearity of the plate photometry. Its reliability suffers from the blending of low non-linear peaks of double stars, while its strong incompleteness is caused by systematic over-compensation of the photometric non-linearity, thus bright galaxies are classified as even brighter stars.

#### 4. The 6dF redshift survey

The strong case for spectroscopic followups of near-IR selected galaxy samples, coupled with the realization that Schmidt telescopes offer wide enough fields to sample most efficiently the sky for shallow samples of  $5\text{--}10\text{ galaxies deg}^{-2}$ , has led the AAO to replace its existing manually-configured FLAIR II 92-fiber system on the UKST with a robotized, 150-fiber system, called 6dF (for Six Degree Field). The 6dF instrument, currently under construction uses an  $r - \theta$  positioner, adapted to the curved focal surface of the UKST.

The AAO has suggested granting 300 nights of dark/grey time during 2001–2003 to a Scientific Advisory Group (6dFSAG, see Acknowledgments, below), to conduct a redshift survey based upon near-IR selected galaxy samples. The 6dFSAG is envisioning a complete spectroscopic followup of  $\simeq 120,000$  DENIS/2MASS selected southern galaxies. The primary sample should be a 2MASS- $K$  or DENIS- $J$  selected sample. Moreover, we will add galaxies to form complete subsamples in DENIS  $I$  and 2MASS  $H$ , as well as SuperCOSMOS  $B$  and  $R$ .

Because fibers cannot be placed closer than  $5'$  to one another, we envision an adaptive tiling scheme, with typically 2 exposures per effective field to minimize the losses due to crowding. At a galaxy density of  $7\text{ deg}^{-2}$ , our  $27\text{ deg}^2$  field will have an average of 189 galaxies. If 10 fibers are reserved for sky, we will have

$2 \times (150 - 10) = 280$  fibers available for objects per field, hence an average of  $280 - 189 = 91$  spare fibers, which we intend to use for other classes of objects such as quasars and/or IRAS galaxies, as well as allow for cosmic variance of the field density.

## 5. The 6dF and DENIS-HI peculiar velocity surveys

The principal motivation of the 6dFSAG is to perform a peculiar velocity survey in the full ( $|b| > 10^\circ$ ) southern hemisphere. Assuming 3/4 dark or grey UKST telescope time and two 4 hours exposures per night, we expect to measure 1 Å resolution spectra for roughly 12,000 ellipticals and lenticulars at  $cz < 15,000 \text{ km s}^{-1}$ . To limit the survey duration, only the densest half of the fields will be observed. The line-widths will be coupled with surface photometry (using DENIS *I* or 2MASS *K* images), to yield distances (with the  $D_n - \sigma$  relation) and hence peculiar velocities. We hope to be awarded the time to pursue the peculiar velocity survey during the period 2003–2005.

In the meanwhile, the DENIS-HI consortium has just begun a spectroscopic followup of DENIS southern galaxies with the Nançay radio-telescope. We estimate that given one-sixth the Nançay time, we can reach the estimated 5000 inclined spiral galaxies at  $-38^\circ < \delta < +2^\circ$  with  $I < 14.5$  and  $cz < 10,000 \text{ km s}^{-1}$  in 2000–2004, thanks to the 5-fold increase in sensitivity and velocity coverage that Nançay should obtain in the fall of 1999. So far, a hundred spectra have been obtained.

## 6. Perspectives

The DENIS-HI and 6dF peculiar velocity surveys should increase the coverage of the southern hemisphere from 1500 to 17,000 galaxies, and within  $cz = 6000 \text{ km s}^{-1}$ , the space density of objects will be 4 times higher than today. Therefore, the problems related to the sparseness of the current peculiar velocity samples should disappear with these two surveys, leading to more accurate estimates of bulk flow,  $\Omega_{\text{matter}}^{0.6}/\text{bias}$ ,  $\Omega_{\text{matter}}$  itself, and especially the primordial density fluctuation spectrum.

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